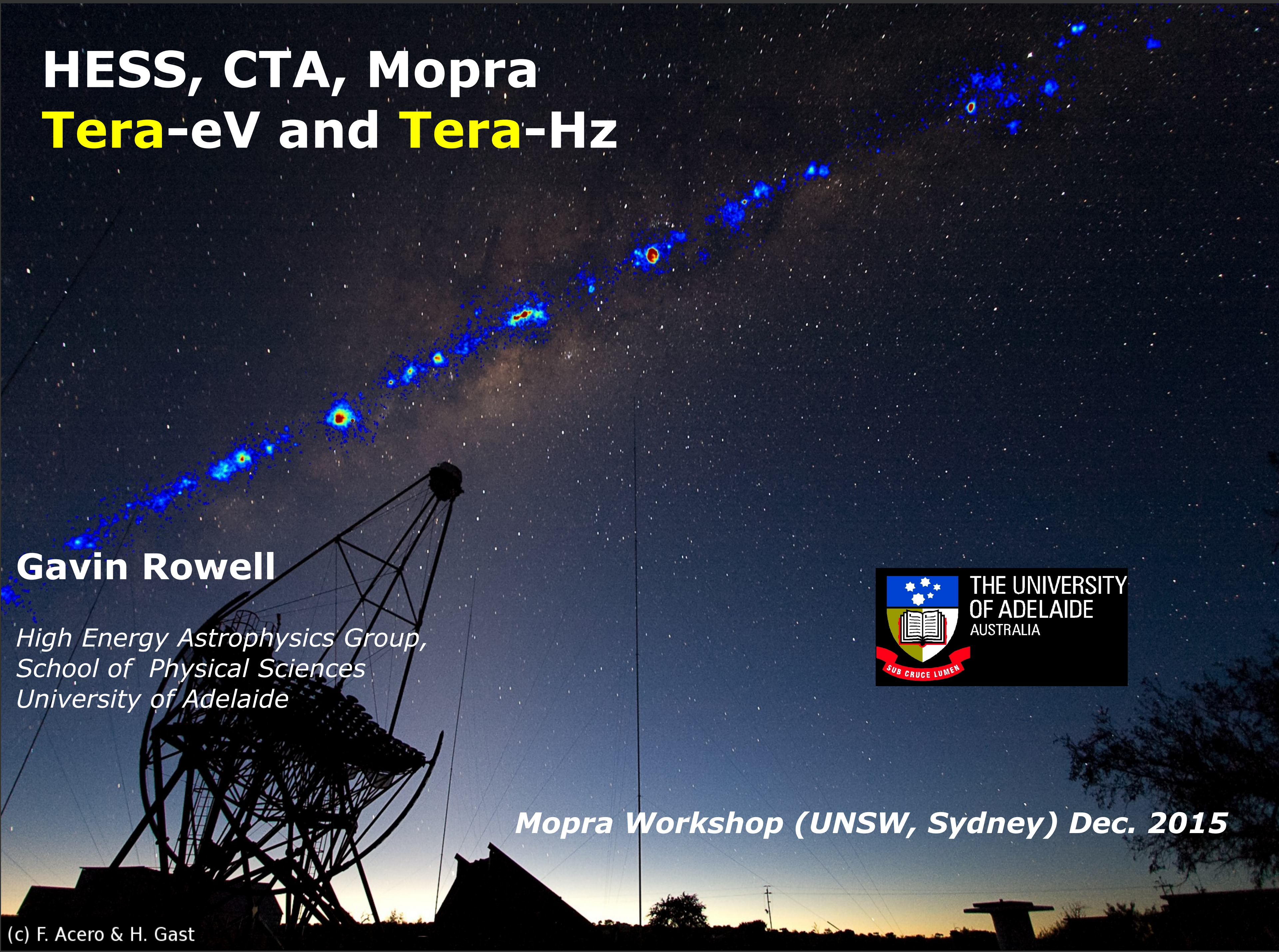


HESS, CTA, Mopra
Tera-eV and Tera-Hz

Gavin Rowell

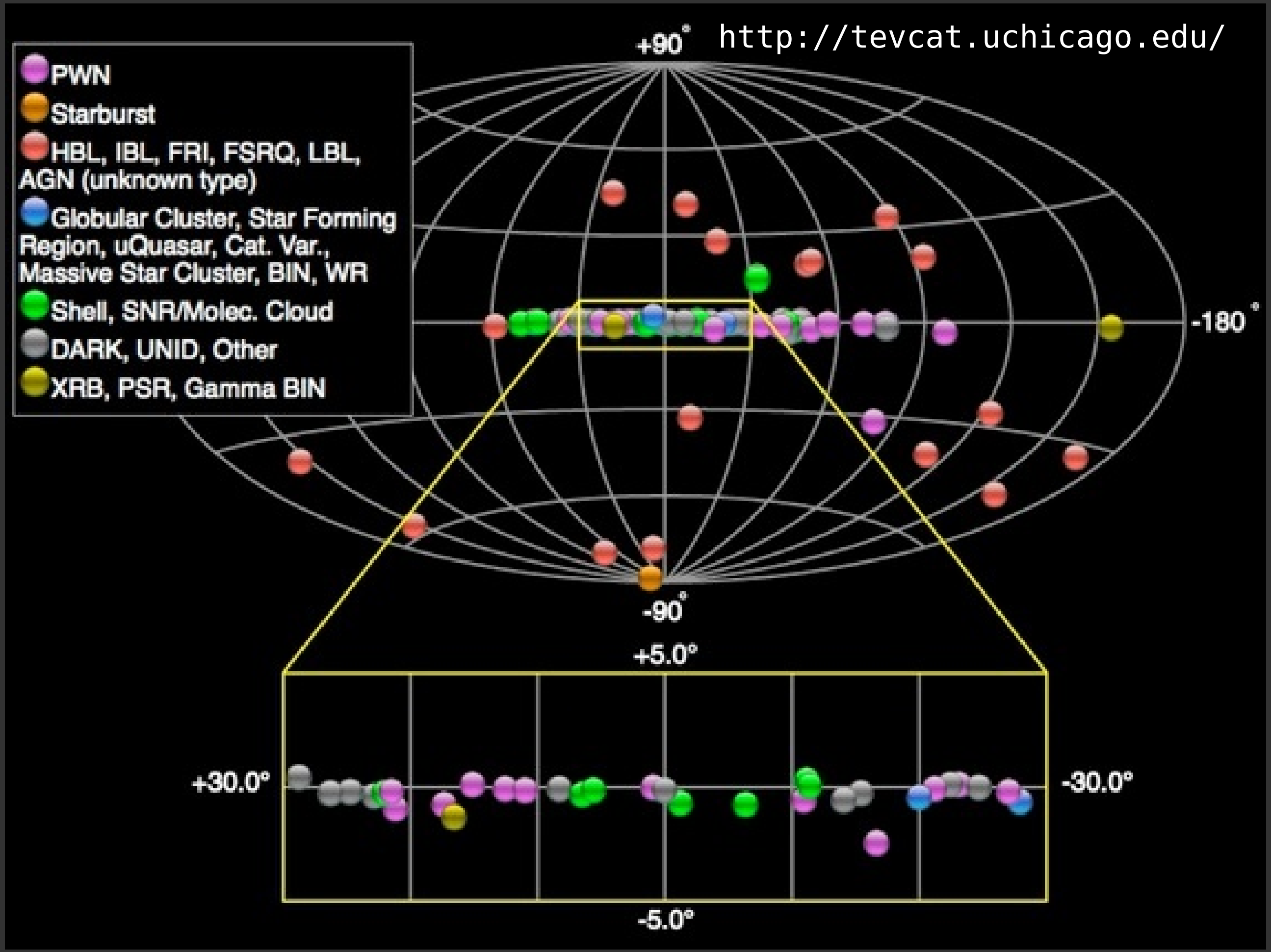
High Energy Astrophysics Group,
School of Physical Sciences
University of Adelaide

Mopra Workshop (UNSW, Sydney) Dec. 2015

Gamma-rays (~30 GeV to ~500TeV)

Highly effective tracer of high energy particles

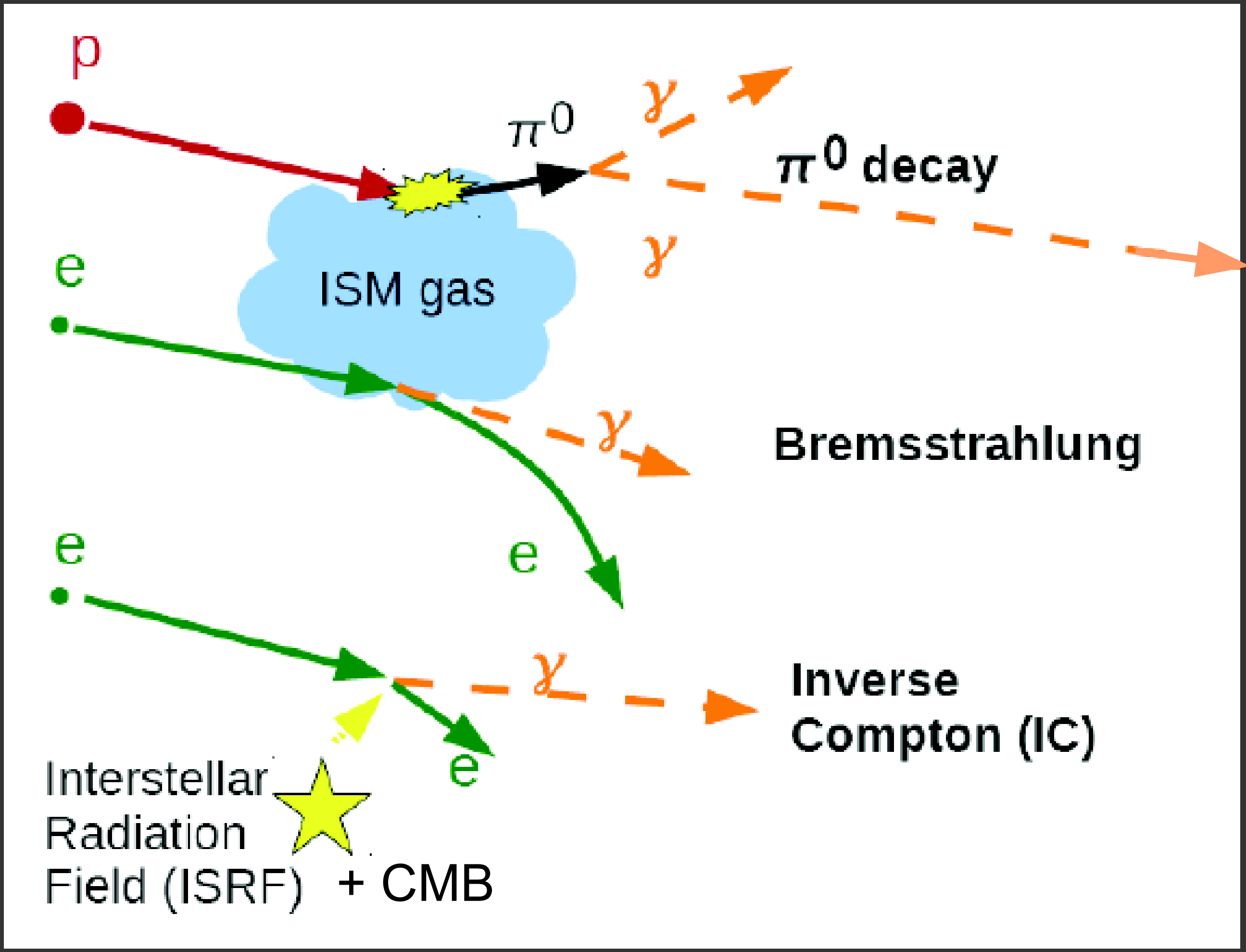
High impact results > 18 Nature, Science, PhysRevLett papers since 2004



Great success with HESS, VERITAS, MAGIC etc.

but we want & need to do more...... HESS-II, MAGIC-II, CTA

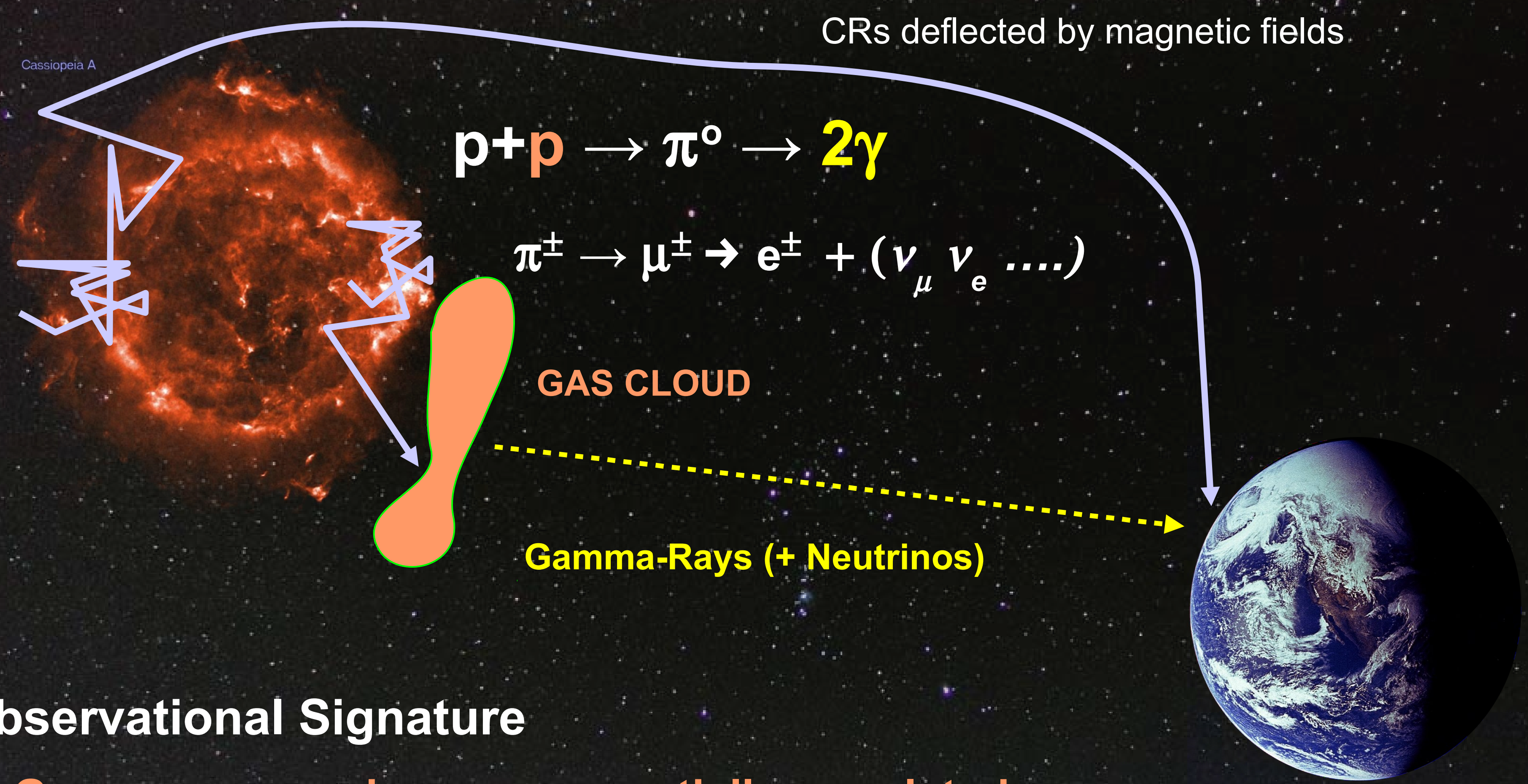
Gamma Rays from multi-TeV particles



Protons: Gamma-rays and gas targets are generally spatially correlated (need to map atomic and molecular ISM)

Electrons: Gamma-ray (IC) + X-ray, radio emission (synch.) coupled (Bremss. usually minor)

Gamma Rays from multi-TeV Cosmic-Rays (p, He ...etc)



Observational Signature

→ Gamma-rays and gas are ~ spatially correlated
(need to measure gas in all chemical states)

→ Intimate connection with mm-radio astronomy (tracing gas)

→ Expected gamma-ray flux F_γ ~ (cosmic-ray density) x (gas mass) / (distance)^2

Why study cosmic-ray (CRs) and electrons?

- Energy density of galactic CRs similar to that in starlight, magnetic fields, and gas kinetic energy

→ these energy densities are all tightly connected.
→ CRs carry energy throughout galaxies
→ CRs intimately linked to evolution of stars and galaxies

- CRs are a signpost of massive stellar evolution

– death (supernova remnants)
– life (winds from massive stars)
– birth (perhaps) signalling onset of fusion/stellar winds
– initiates astro-chemistry → life!

- Where do magnetic fields come? Are they important?

– Magnetic fields can greatly influence star formation!
– CRs can create magnetic fields - they ionise atoms

- CRs and electrons trace outflows and jets

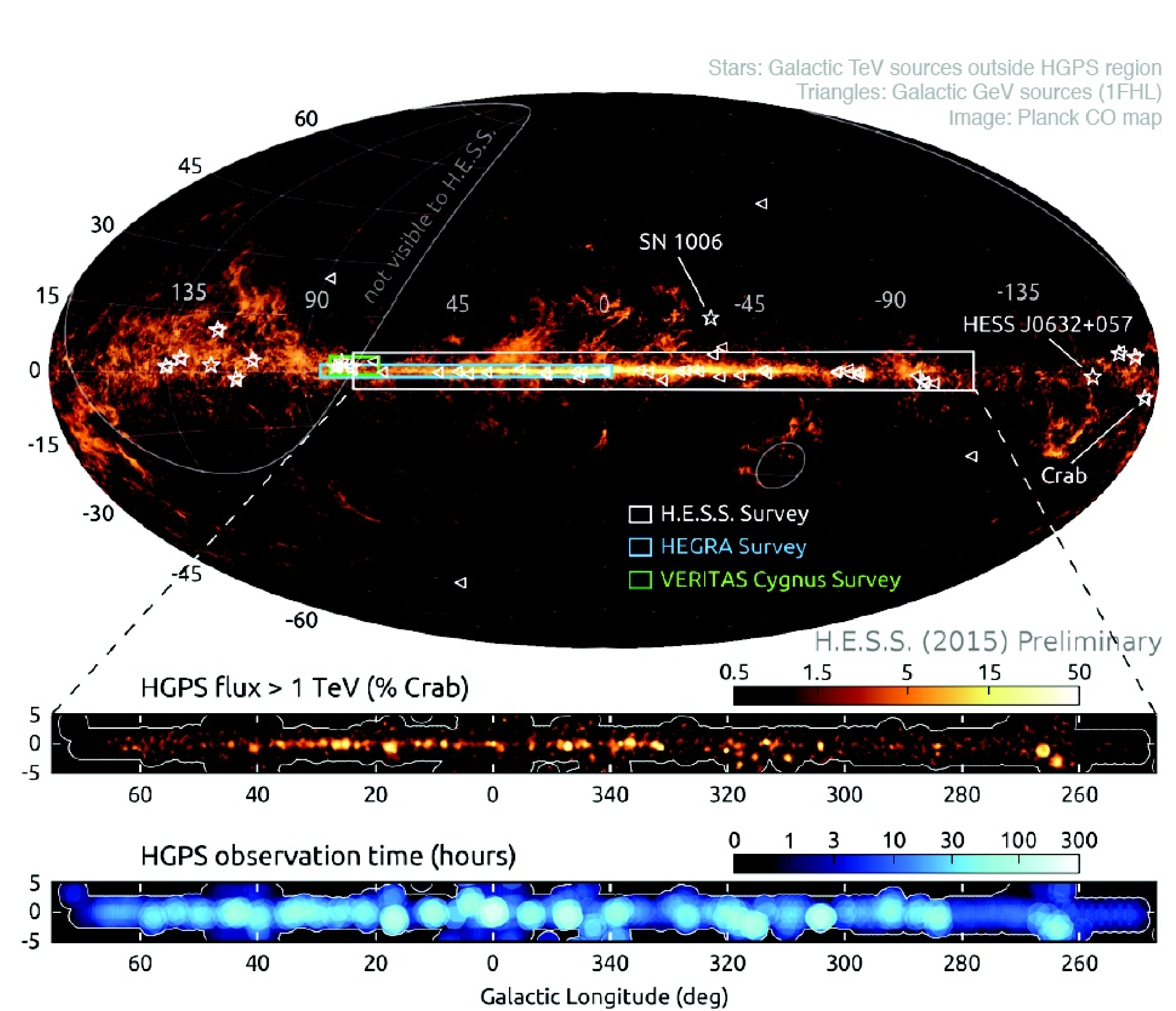
– jets, pulsar winds, accretion, GRBs-hypernovae.....

H.E.S.S TELESCOPES (NAMIBIA)

4 x 107 m^2 (since 2003)
1 x 614 m^2 (since 2012)

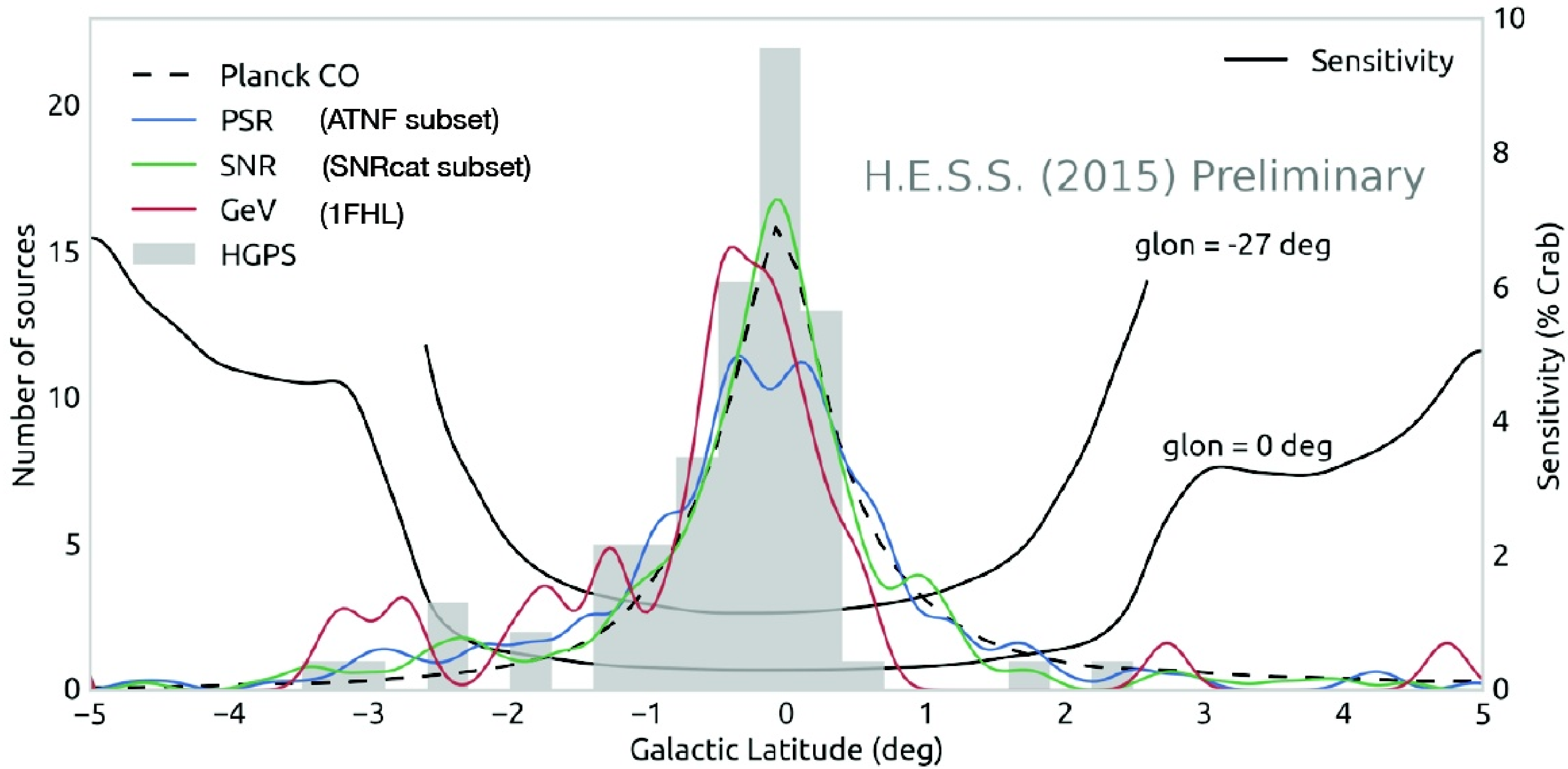
HESS Galactic Plane Survey (HGPS) – 2015 Update

Deil et al 2015



Christoph Deil, ICRC 2015, "H.E.S.S. Galactic plane survey" — Slide 4

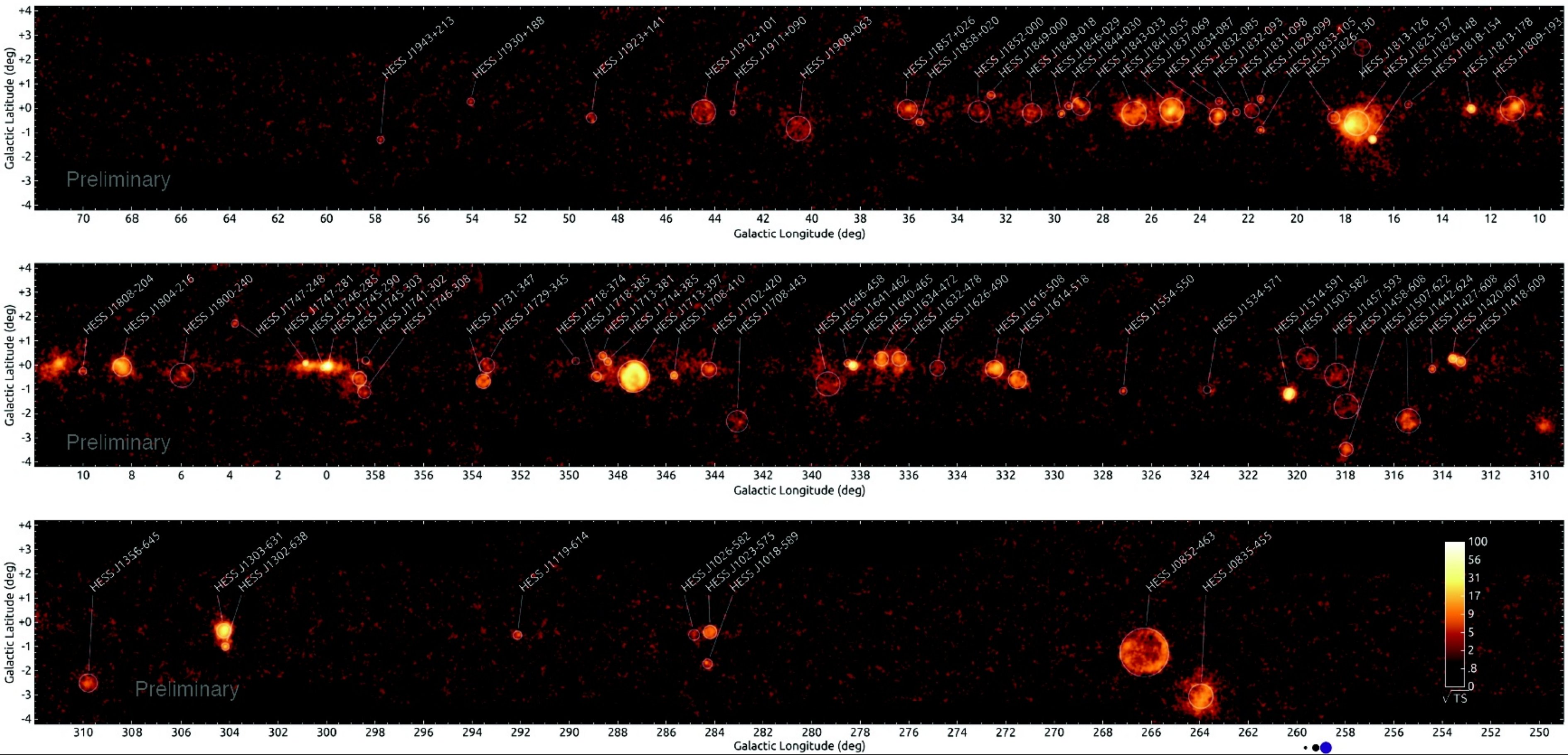
Latitude Distribution - HGPS Sources et al.



HESS Galactic Plane Survey (HGPS) – Skymaps

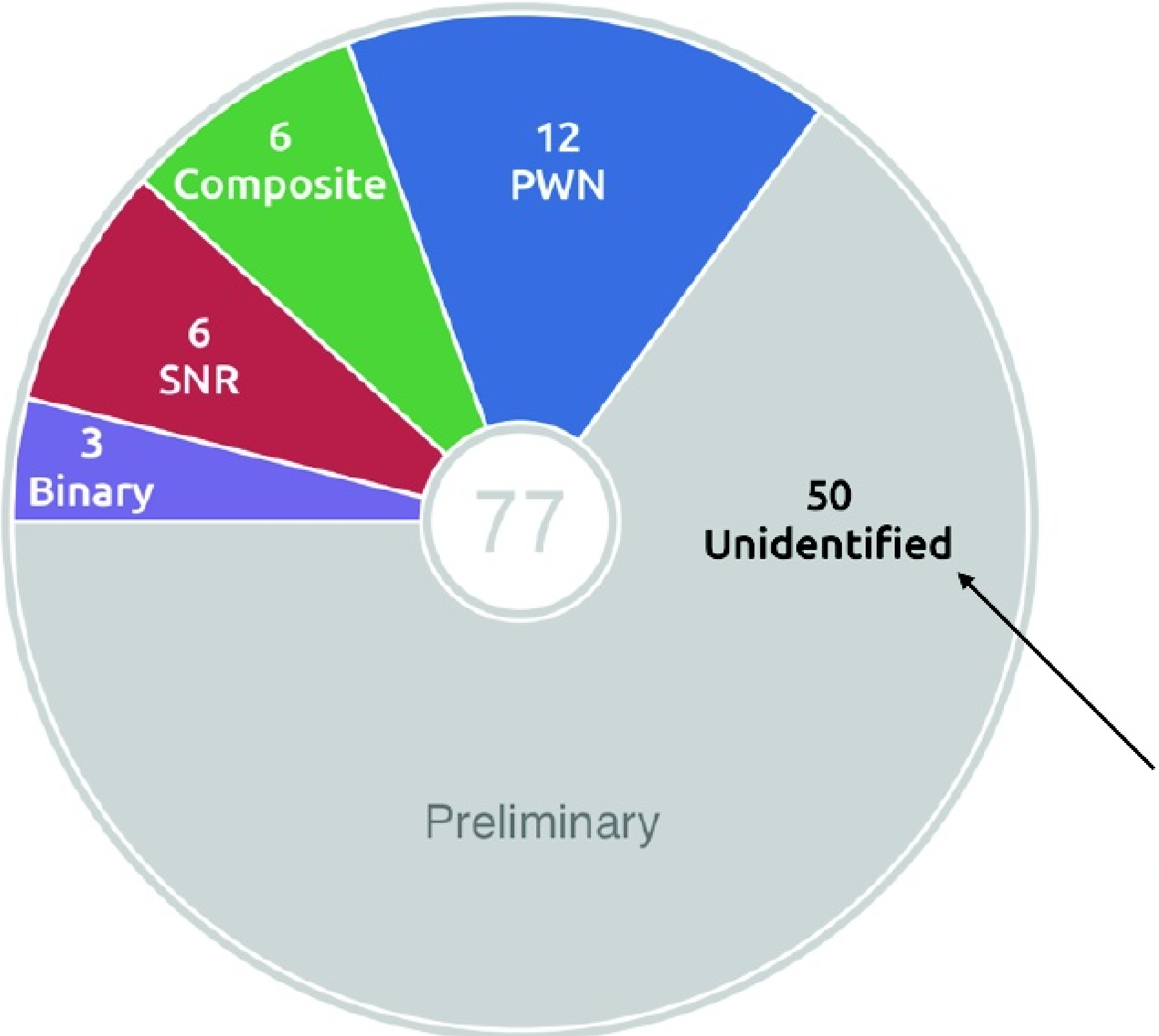
→ 77 sources (13 new sources)

Deil et al 2015



HGPS Gamma-Ray Sources – What are they?

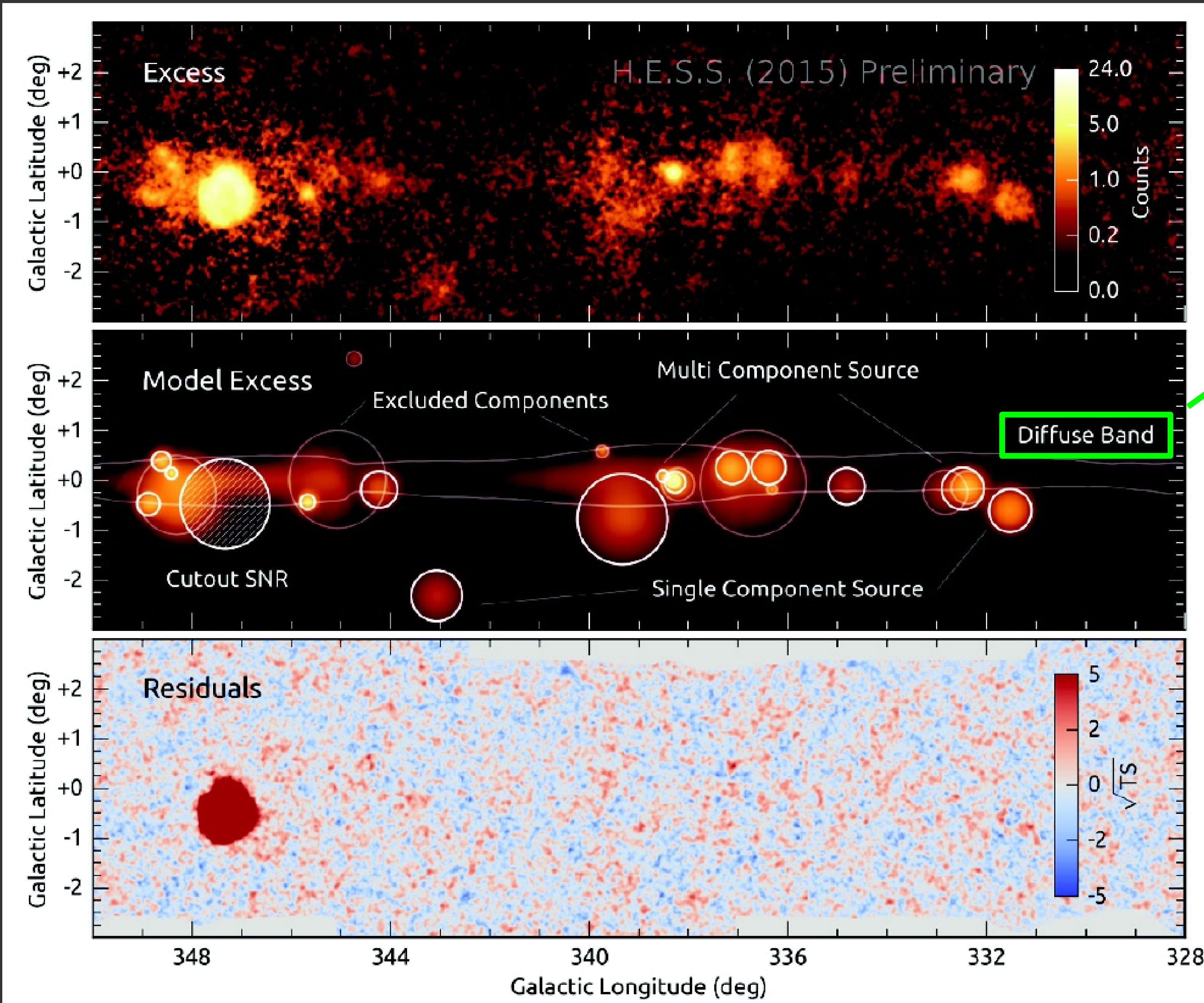
Deil et al 2015



Mostly sources with multiple associations

HESS Data Analysis → HGPS Catalogue

Deil et al 2015



Diffuse Component Required.

→unresolved sources?

→ from 'sea' of CRs?

Diffuse component also required

In CMZ

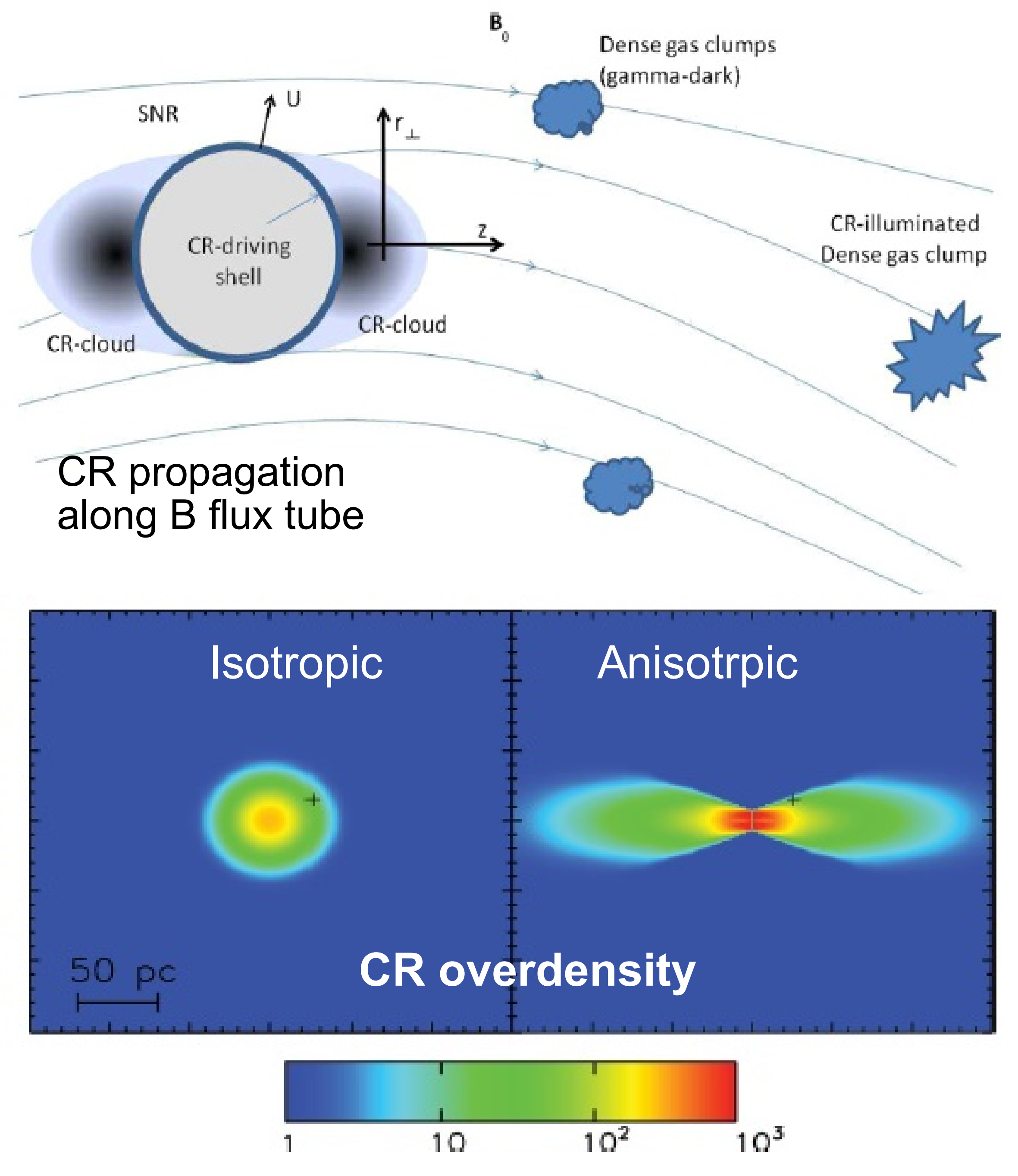
Lemiere etal 2015

Earlier Plane Analysis

Aharonian etal 2014

CRs escaping an accelerator. diffusion – not necessarily Isotropic!

Malkov etal 2013
Nava & Gabici 2013



→ Nearby clouds will see different CR densities

→ Need detailed maps of ISM gas + B-field direction

CR Diffusion *Into* Molecular Clouds

Gabici etal 2007

R = distance CR travels into molecular cloud core

$$R = 0.62 - \sqrt{6D(E_P, B)[1600 - t_0]} \quad [\mathrm{pc}]$$

$$D(E_P, B(r)) = \chi D_0 \left(\frac{E_P/\mathrm{GeV}}{B/3\,\mu\mathrm{G}} \right)^{0.5} \quad [\mathrm{cm}^2\,\mathrm{s}^{-1}],$$

$$B(n_{H_2}) \sim 100 \sqrt{\frac{n_{H_2}}{10^4\ \mathrm{cm}^{-3}}} \quad [\mu\mathrm{G}]$$

χ=diffusion suppression

→ Low energy CRs can't reach cloud core

→ Expect harder TeV spectra from cores.

→ ***Don't expect electrons to penetrate!!***
(due to sync. losses)

→ **Need to map dense cloud cores**

The Cherenkov Telescope Array

- Huge improvement in all aspects of performance

  x10 better sensitivity, better FoV + angular resolution, wider energy coverage, collection area >few km^2, wider survey capabilities

- A user facility / proposal-driven observatory

  CTA Consortium time (Key Science Projects) to lead off

- An international project ~ €200M

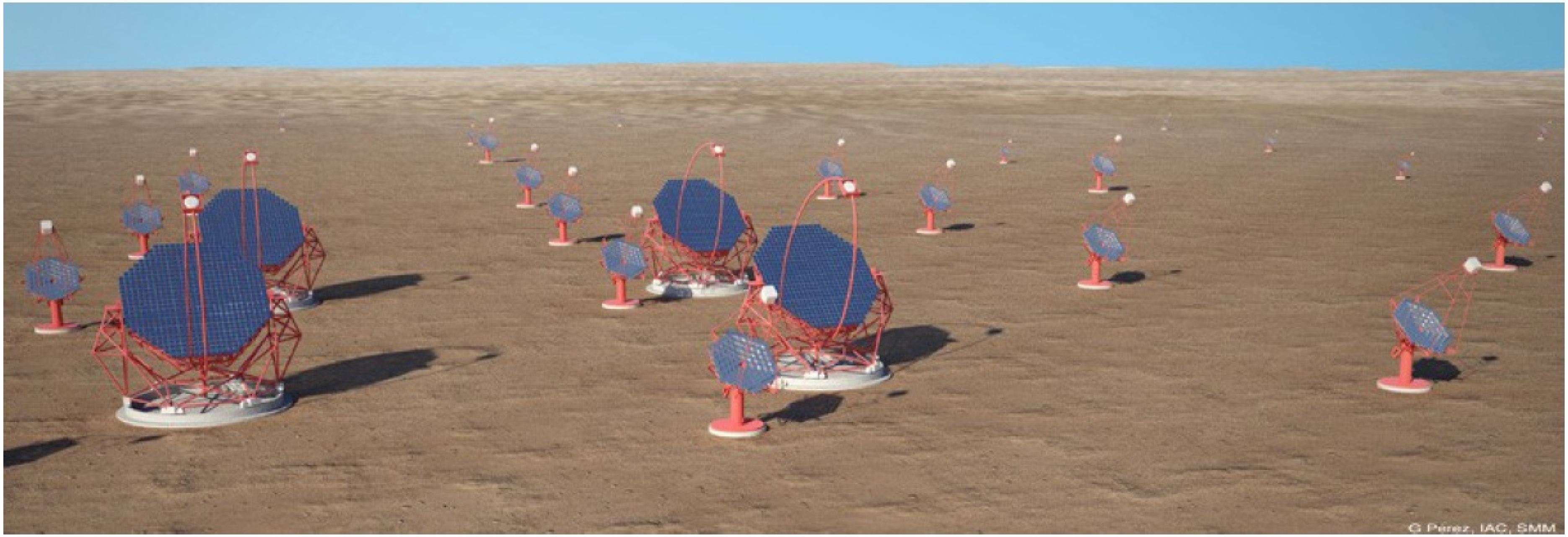
  Involves >90% of current TeV gamma-ray scientists + many others

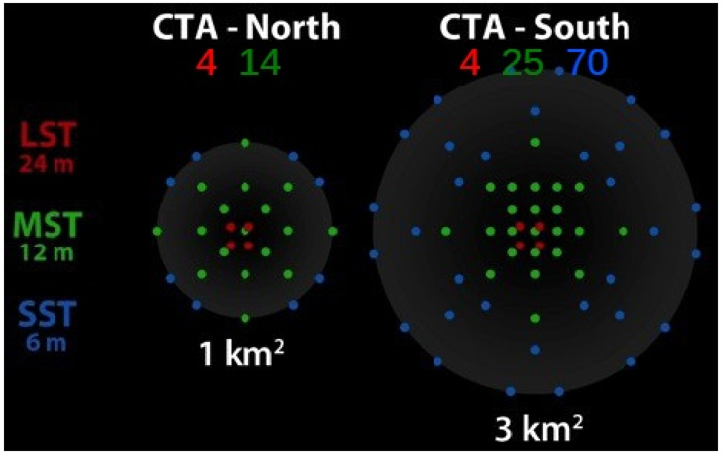
- CTA-S South (~120 telescopes)

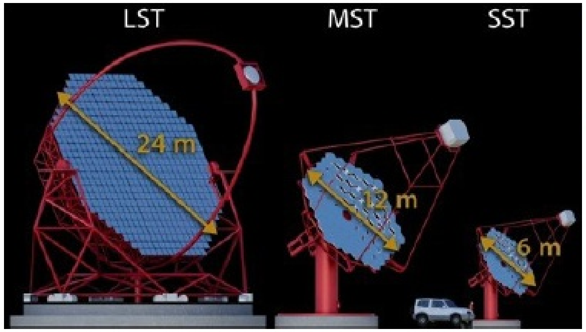
  CTA-N North (~25 telescopes)

https://www.cta-observatory.org/

The CTA Observatory

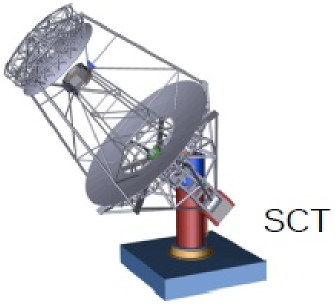


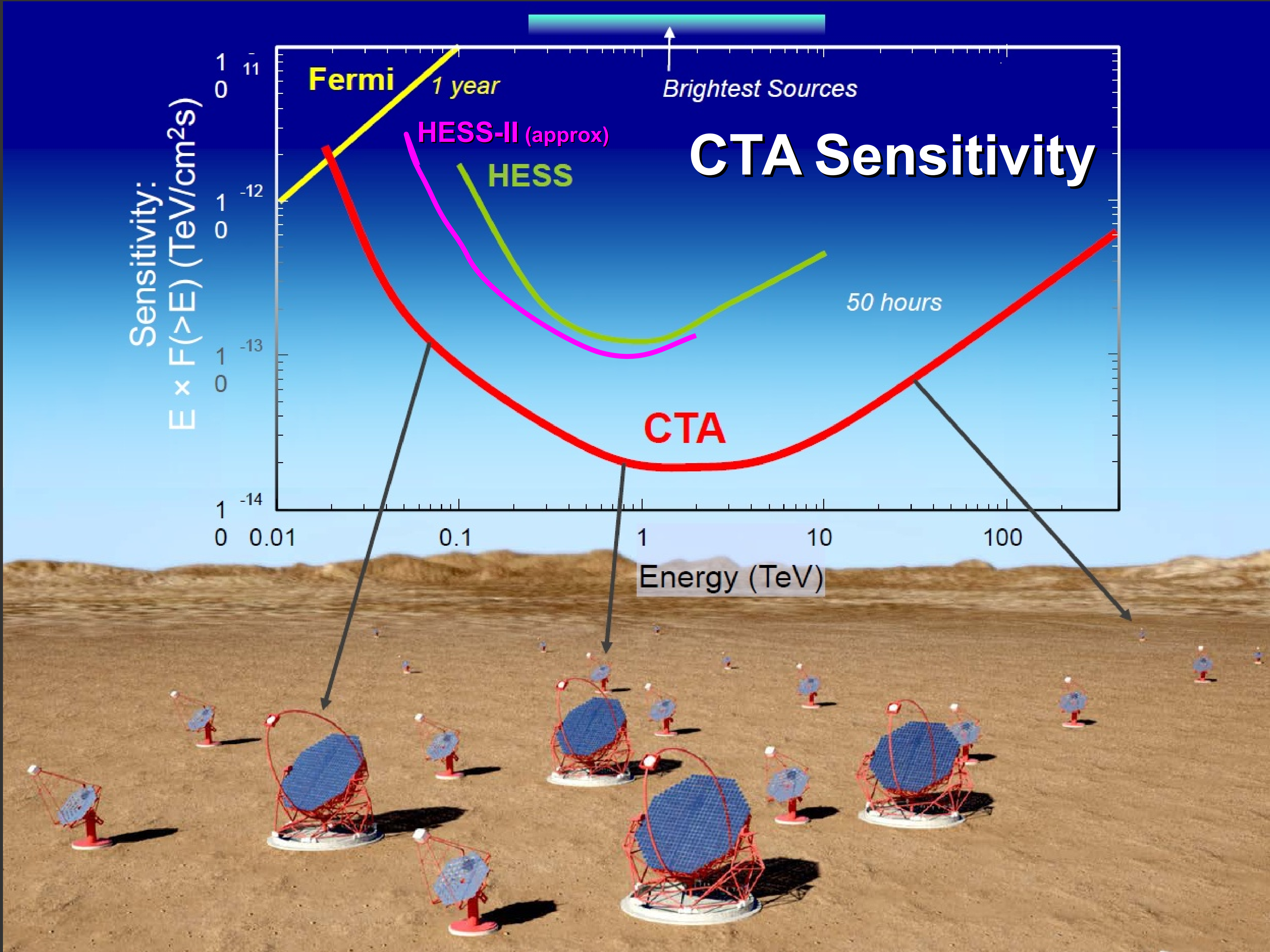




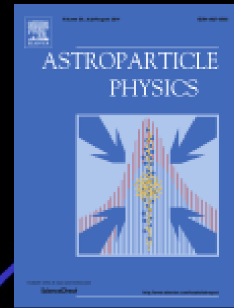
Characteristics

3 telescope classes
2 sites (South and North)
About 120 (+25) telescopes



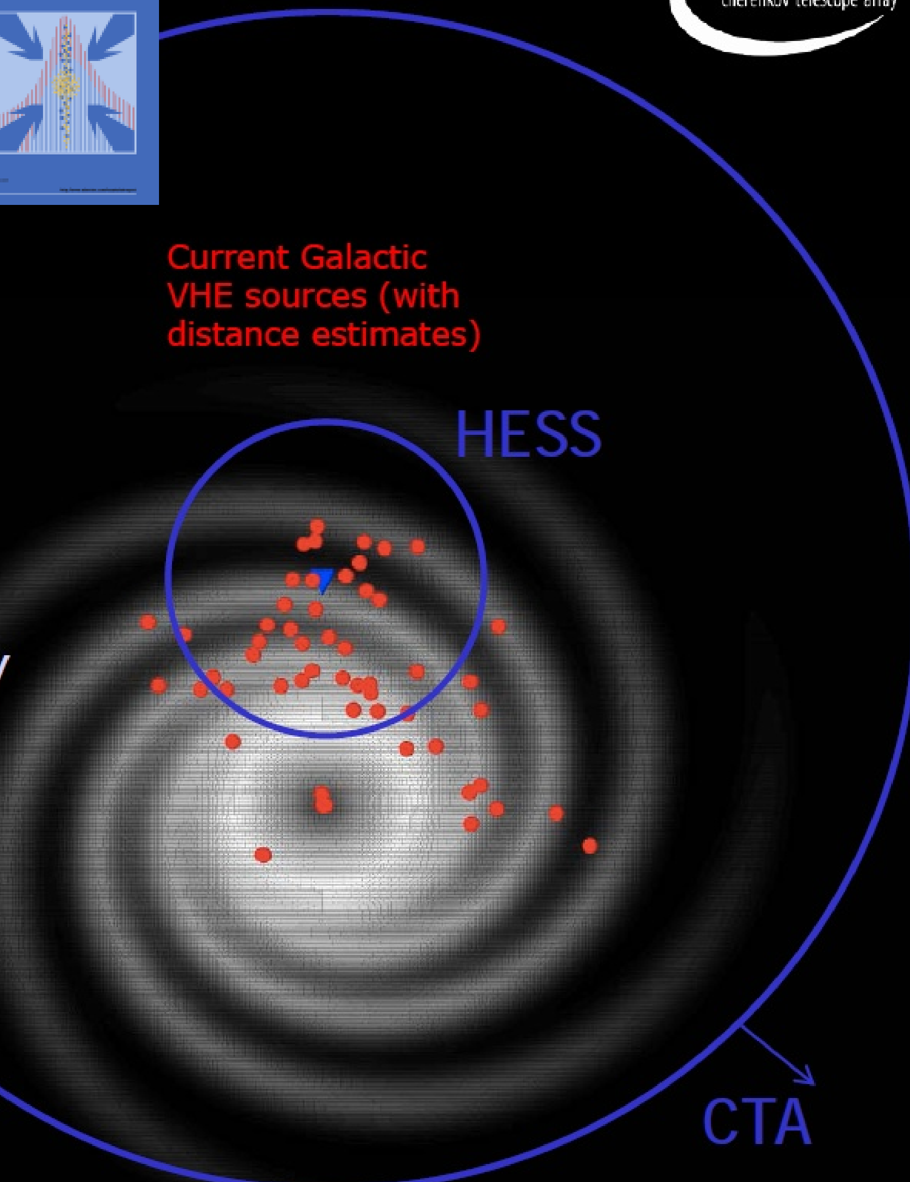

CTA Sensitivity
Fermi
1 year
Brightest Sources
HESS-II (approx)
HESS
50 hours
CTA
Sensitivity: E × F(>E) (TeV/cm²s)
10^-11
10^-12
10^-13
10^-14
0.01
0.1
1
10
100
Energy (TeV)

CTA Science



Special Issue Vol 43, Pg 1-356 (Mar 2013)

- e.g. Galactic objects
  - Newly born pulsars and the supernova remnants
    - have typical brightness such that HESS etc can see only relatively local (typically at a few kpc) objects
  - CTA will see **whole** Galaxy
- Survey speed ~300×HESS



Extragalactic

AGN z>0.5, GRBs, Star-bursts, Gal. clusters, AGN haloes..

Astro-particle

Dark matter, Lorentz invariance....

Optical

Intensity Interferometry

CTA Time-line & Funding

cta
cherenkov telescope array

- Design Study
  - Design development 2006-9
  - CTA appears on *key roadmaps*
- Preparatory Phase > €30M funded
  - EU FP7 funded activity 2010-14
  - Preliminary Design Review 2013
  - Site Selection during 2014
  - Critical Design Rev. early 2015
- Construction Phase
  - Site development and first telescopes on site 2015/16
  - First science 2016/17
  - Completion ~2020
- Operation: aim for 30 years

Pre-production phase

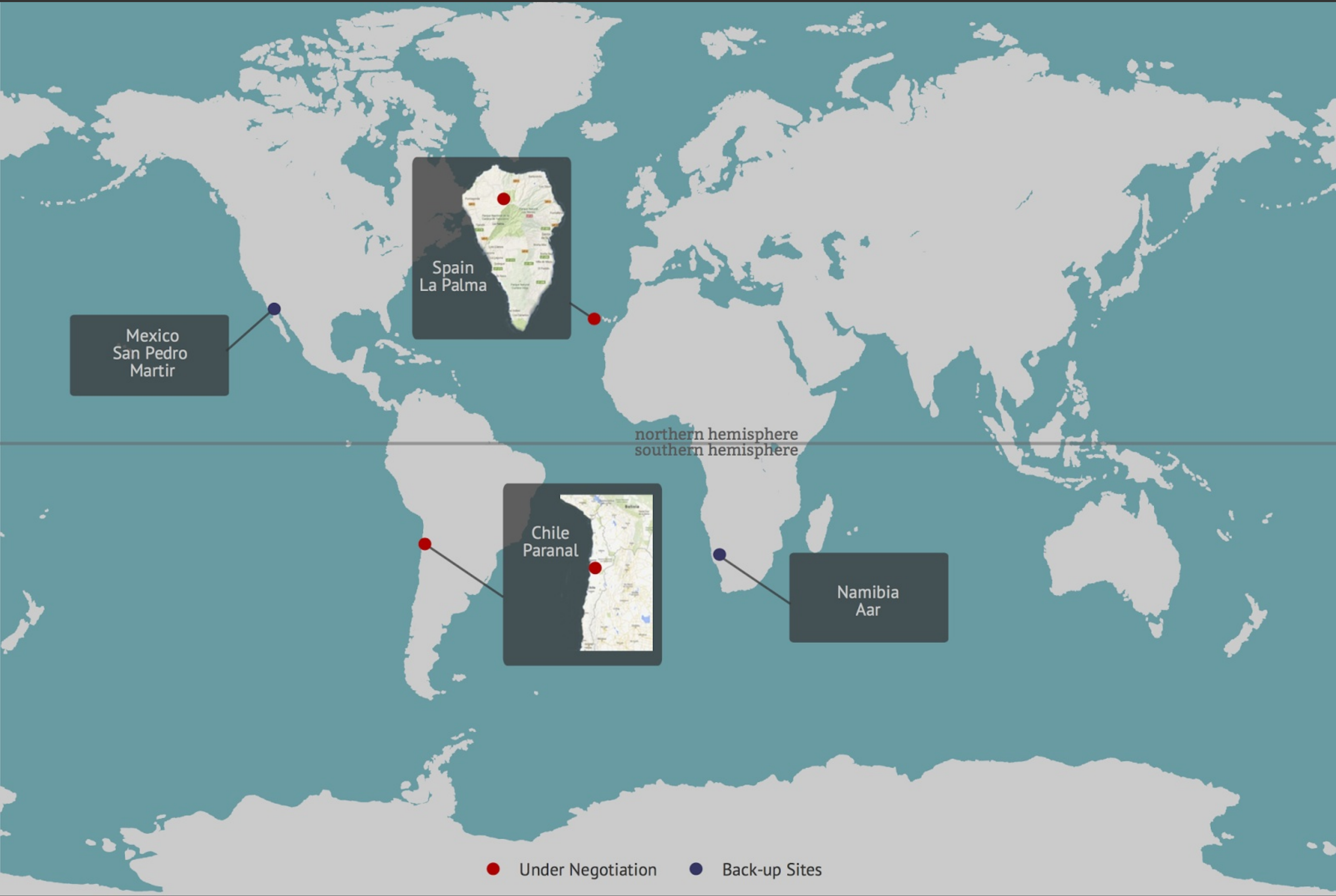
ESFRI
European Strategy Forum
on Research Infrastructures

7 April 2014

additional projects which we recommend for support from the Member States and from suitable Horizon 2020 instruments to help reach the Innovation Union target of 60% of projects being in implementation by 2015:

ECCSEL, EISCAT-3D, EMSO, BBMRI, EL, CTA, SKA, CLARIN and DARIAH

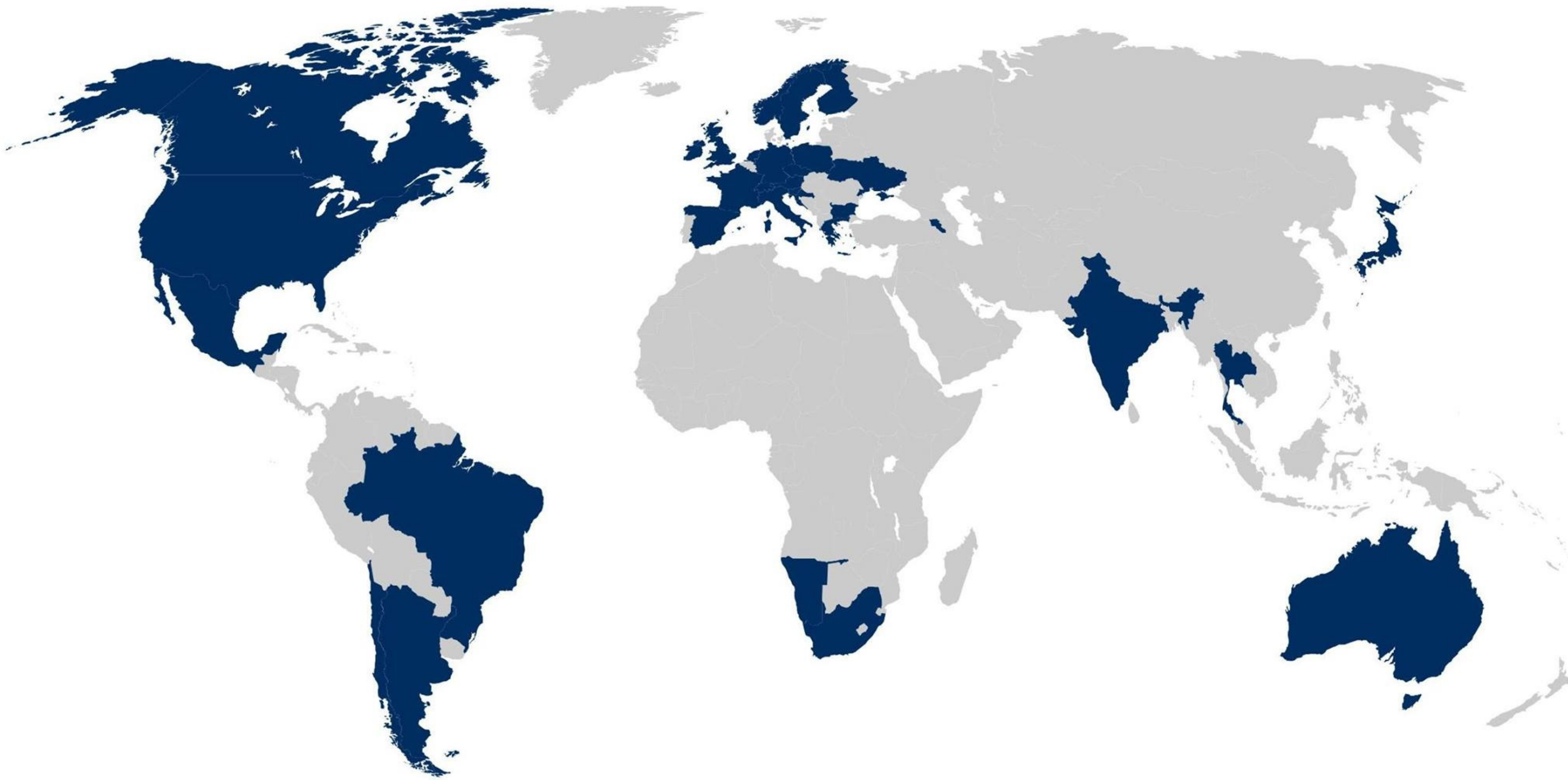
CTA Site Preferences (North & South) Chosen July 2015



CTA Consortium – Sept. 2015

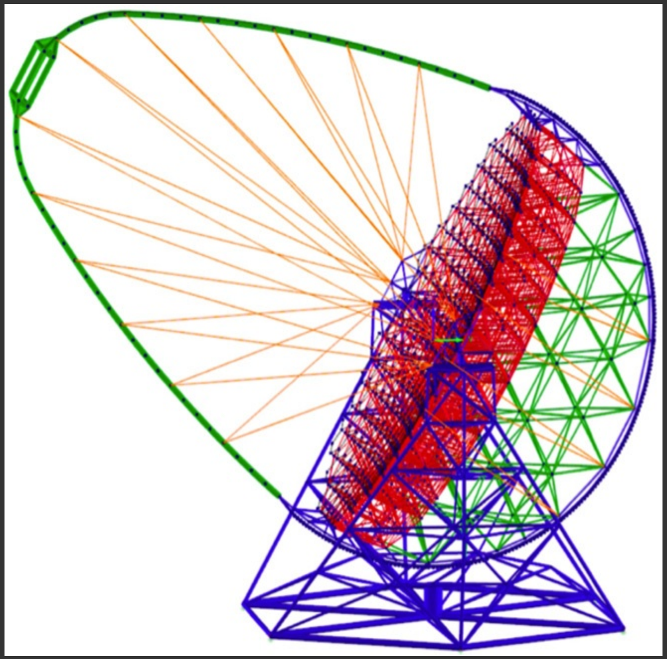
- 32 countries

>200 institutes (Australia – U.Adel., UNSW, UWS, U.Syd., ANU, Monash)

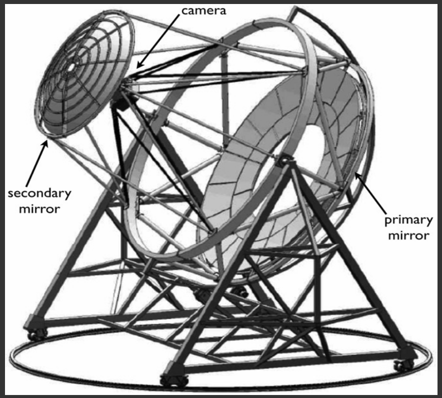


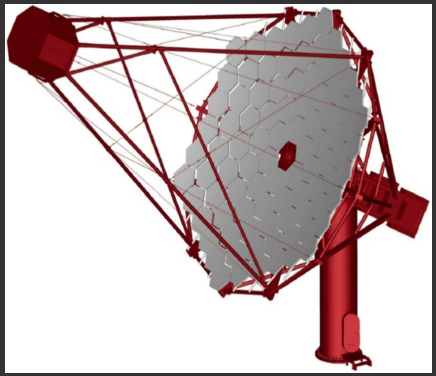
CTA – Telescopes

LST

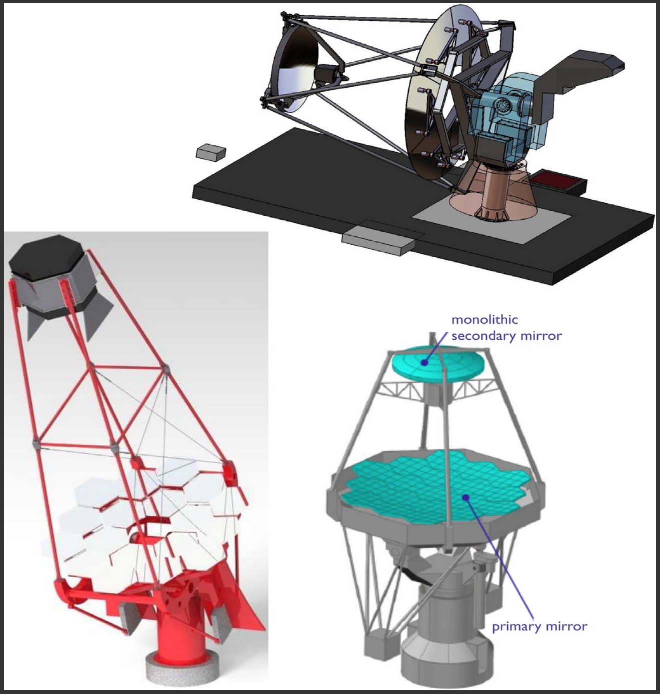


MST





SST



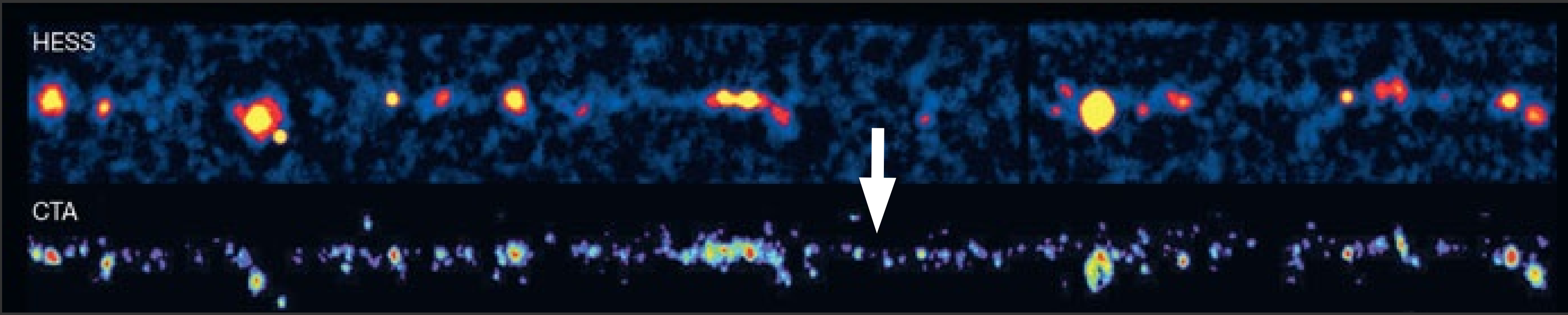
LST – Large Size Telescope 23m diam 4.5° FoV
MST – Medium Size Telescope 12m diam 7.5° FoV
SST – Small Size Telescope 4-6m diam 9° FoV

prototypes now under construction

GCT Prototype (Small Size Telescope) – Dec. 2015 Paris

Australia - ARC LIEF 2015 support for GCT hardware and commissioning.

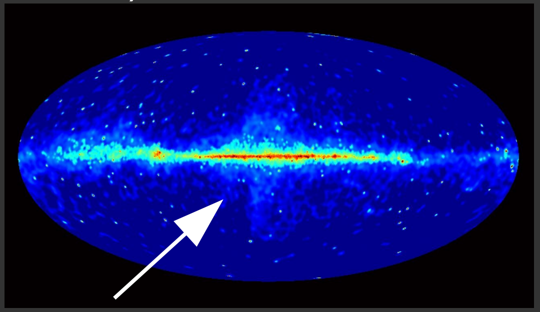
Galactic Plane TeV Surveys : Major Issue



Funk et al 2012

- CTA will provide Galactic Plane TeV Gamma-ray maps
  on ~1-3 arc-min scales
  (~0.5 arc-min possible – high quality cuts)

- >3 sources per deg^2 |b|<0.2^o |l|<30^o (Dubus etal 2013)



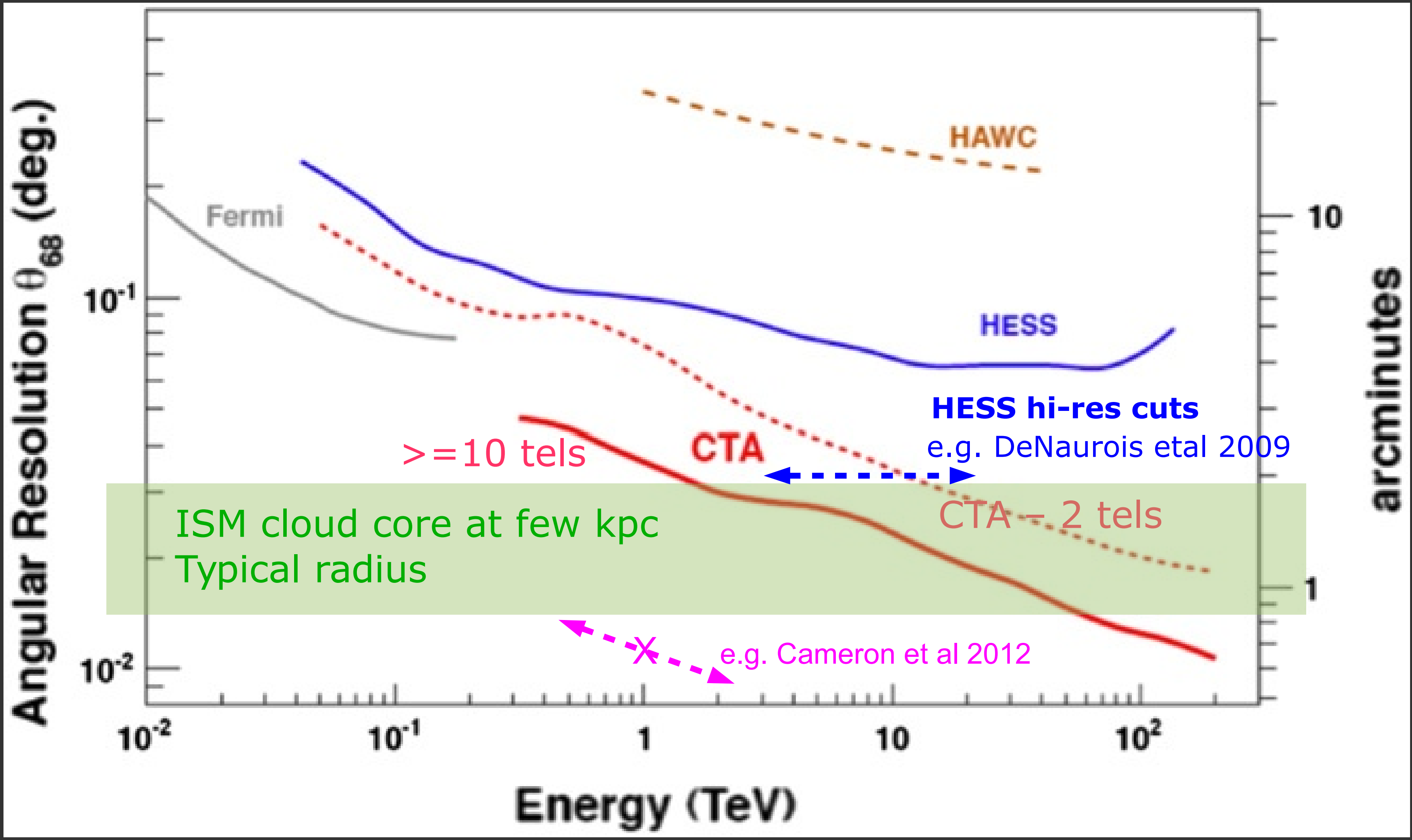
- Diffuse TeV components visible?
  from CR 'sea' – maybe
  local CR accelerator enhancements – yes

Confusion guaranteed (same as for Fermi-LAT at GeV energies!)

- Mapping the ISM on arc-min scales over the plane will be essential
Mopra (CO, CS), Nanten2 (CO), ASKAP (HI, OH), THz (CI, C+)

Angular Resolution (HESS, CTA..)

Acharyara etal 2013



CTA MST-SCTs with small pixels and/or hi-res cuts → resolve cloud cores!

We need to map the interstellar gas to discriminate hadronic vs. leptonic gamma-rays!

HI (atomic H), OH

CO

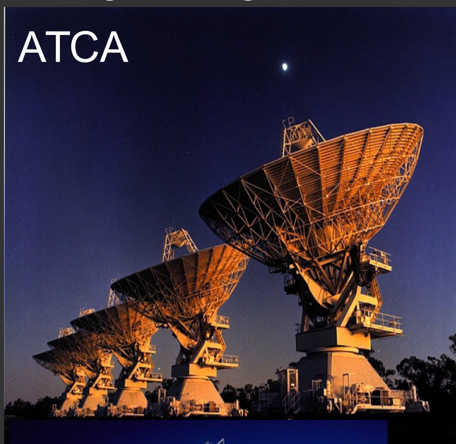
CO, NH_3, CS, SiO...

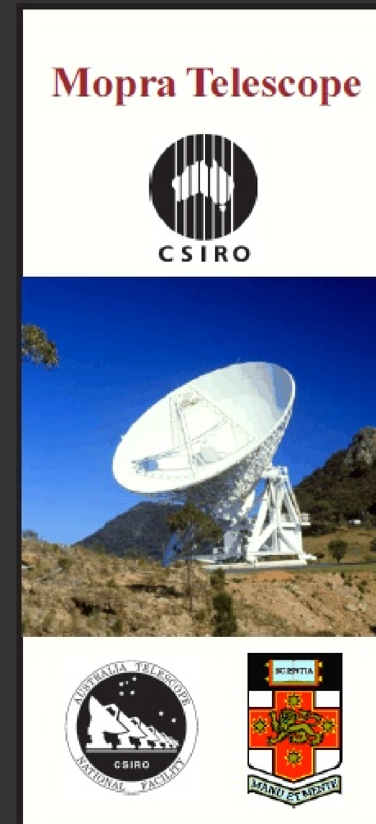
<u>Gas density</u>

~$10^{1 \text{ to } 2}$ cm^{-3}

~$10^{2 \text{ to } 3}$ cm^{-3}

>$10^{2 \text{ to } 4}$ cm^{-3}





HEAT – THz telescope (Antarctica) [CI] + [CII]

→ tracing the complete C budget!

CTA: Australia's Roles.
We play to our strengths!

CTA Hardware & Array Design

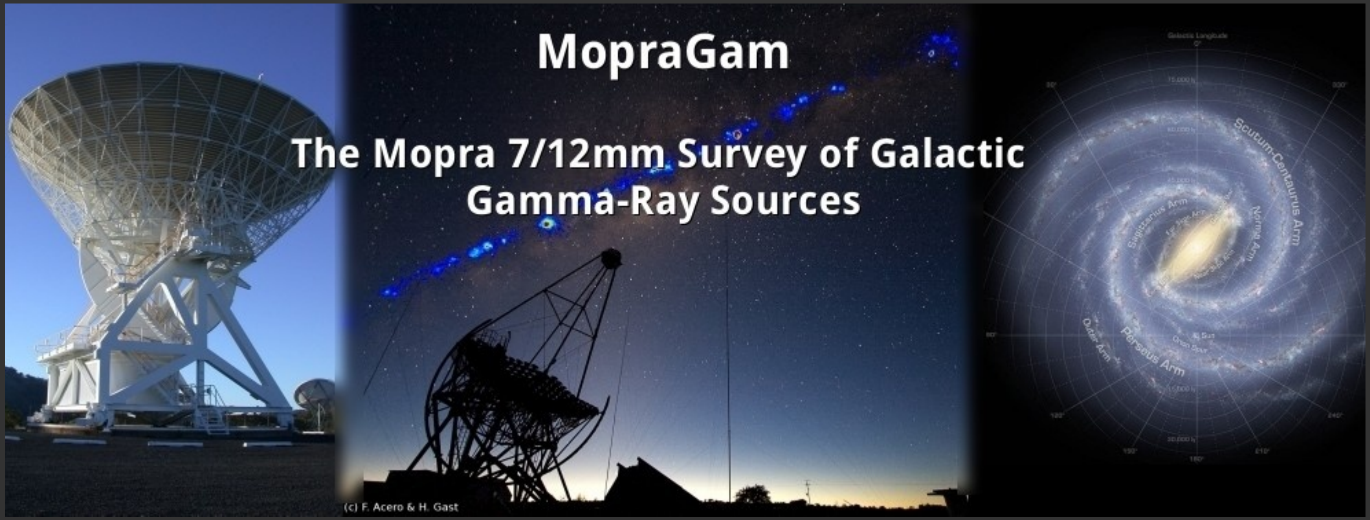
- Array layout and analysis techniques (E>10 TeV)
- Camera hardware (for small telescopes) ARC LIEF ($465k)
- Atmospheric characterisation (LIDAR, cloud monitoring)
- Effect of clouds on Cherenkov images

Multi-wavelength Support

- ISM surveys/studies (Mopra, ASKAP, HEAT)
- Radio continuum studies (ASKAP, MWA, SKAMP, SKA....)
- X-ray astronomy (e-ROSITA, XMM, Chandra)

Theory

- Theoretical high energy astrophysics
  (e.g. Galactic Centre, AGN jets/outflows)
- Astro-particle physics – Dark matter properties

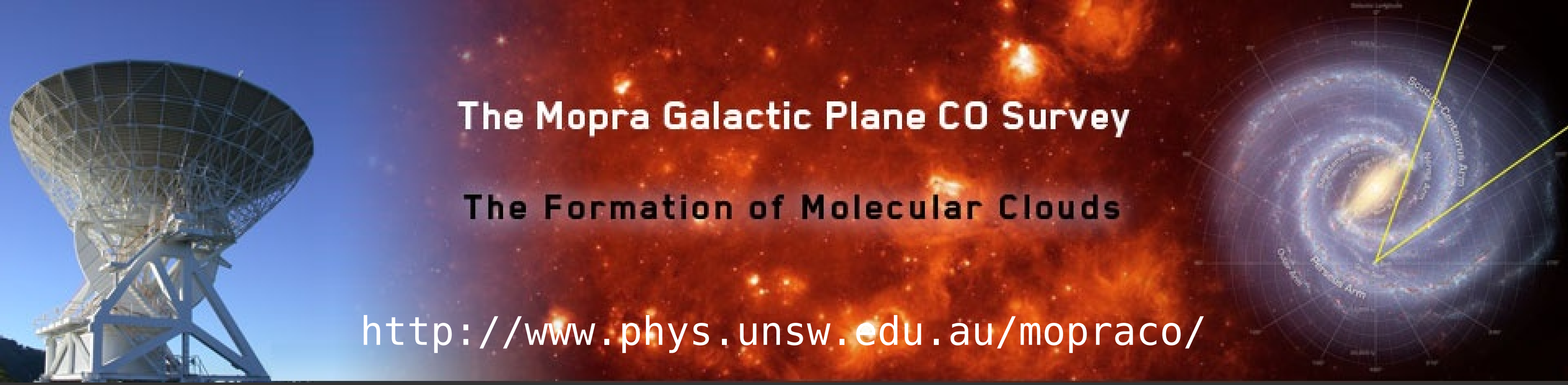


http://www.physics.adelaide.edu.au/astrophysics/MopraGam/

Team Members
Gavin Rowell (lead, Adelaide), Michael Burton (UNSW), Yasuo Fukui (Nagoy), Bruce Dawson (Adelaide), Andrew Walsh (Curtin), Felix Aharonian (DIAS/MPIK), Stefan Ohm (Leicester)
Adelaide PhD students: Brent Nicholas (now at DSTO), Nigel Maxted (Montpellier → UNSW), Phoebe de Wilt, Jarryd Hawkes, Fabien Voisin, Jame Lau, Rebecca Blackwell, Stephanie Pointon (MPhil).

Targets
Since 2012 observed over ~40 TeV gamma and high energy sources, > 1500 hrs.

Student Projects
Phoebe deWilt – ISM survey of unidentified TeV sources, TeV+HII regions
Jarryd Hawkes – Outflow sources (e.g. XRBs) and magnetars
Fabien Voisin – Pulsar Wind Nebulae
James Lau – SNR/MC associations / G328 filament
Rebecca Blackwell – CMZ
Stephanie Pointon – Two bright unidentified TeV sources



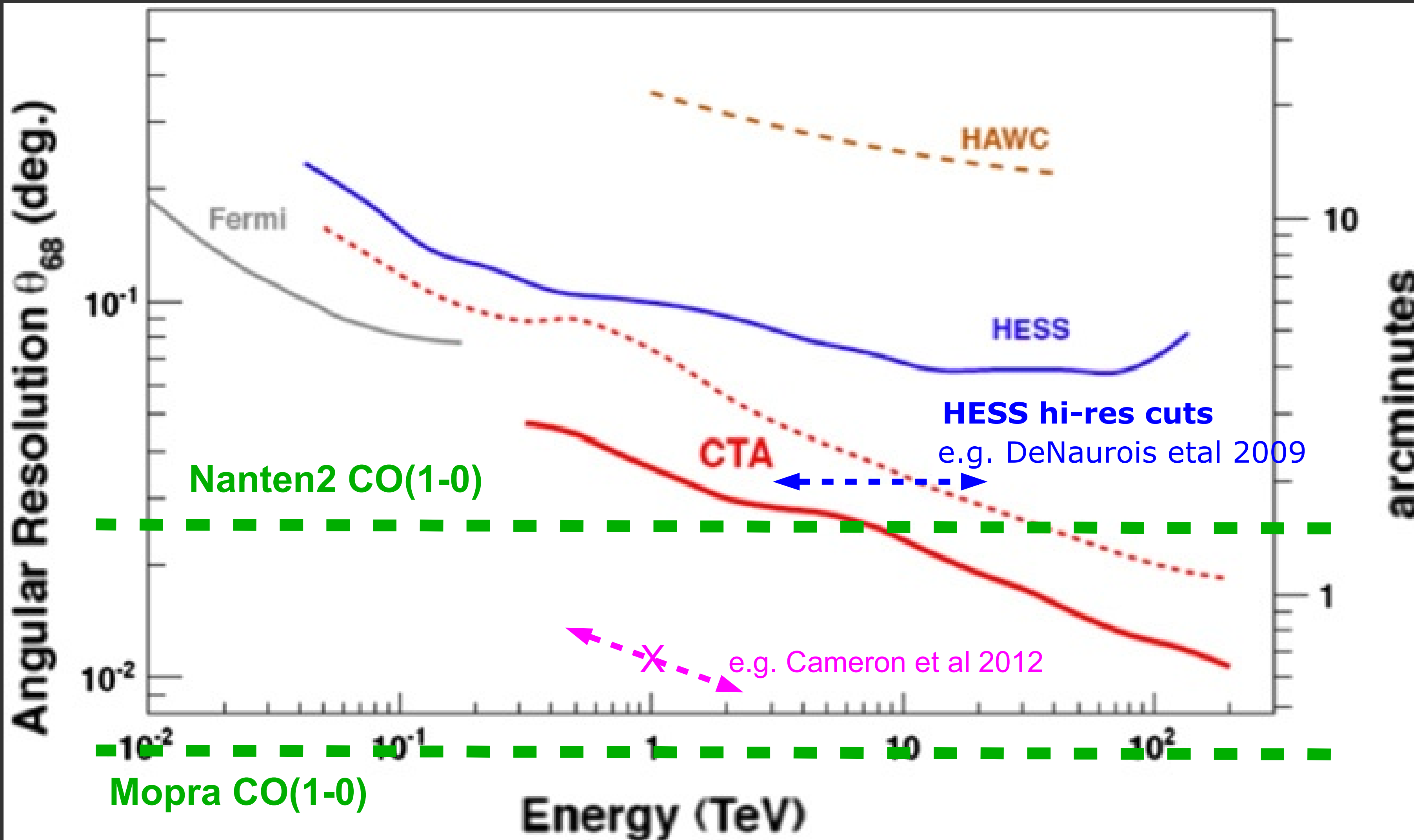
IF	Frequency (GHz)	Isotopologue	V_{low} (km/s)	V_{high} (km/s)
1+2	110.1	^{13}CO (1-0)	-475	+270
3+4	109.7	$C^{18}O$ (1-0)	-495	+255
5	112.3	$C^{17}O$ (1-0)	-235	+130
6+7+8	115.2	^{12}CO (1-0)	-550	+525

~35” Beam @ ~0.1 km/s resolution

Complementary to new Nanten2 CO surveys

Angular Resolution (HESS, CTA..)

Acharyara etal 2013



Beam Sizes 68% containment radius

Tera eV & Hz – The Next Steps

2008-2014 Adelaide-led 7/12mm targeting now ~ complete

3mm CO survey extensions
TeV SNR shell surrounds (RXJ1713, VelaJnr, HESSJ1731)

2015
- Completed 7mm mapping of most bright TeV sources
- CO survey extensions (CCC, TeV SNRs, PWNe...)

2016-2018?   Mopra LIEF

- Complete CO survey b<=+-1.0deg..
- Prepare CO cubes for diffuse gamma-ray models

- CTA Key Science Projects
  TeV SNRs, CMZ, Gal. Cen, HESS-PeVatrons, LMC

Ctitical underpinning/legacy for HESS, CTA, Fermi-LAT


Thank you..
(c) F. Acero & H. Gast